Low Background Phase of KamLAND

Andreas Piepke
University of Alabama

The KamLAND Collaboration

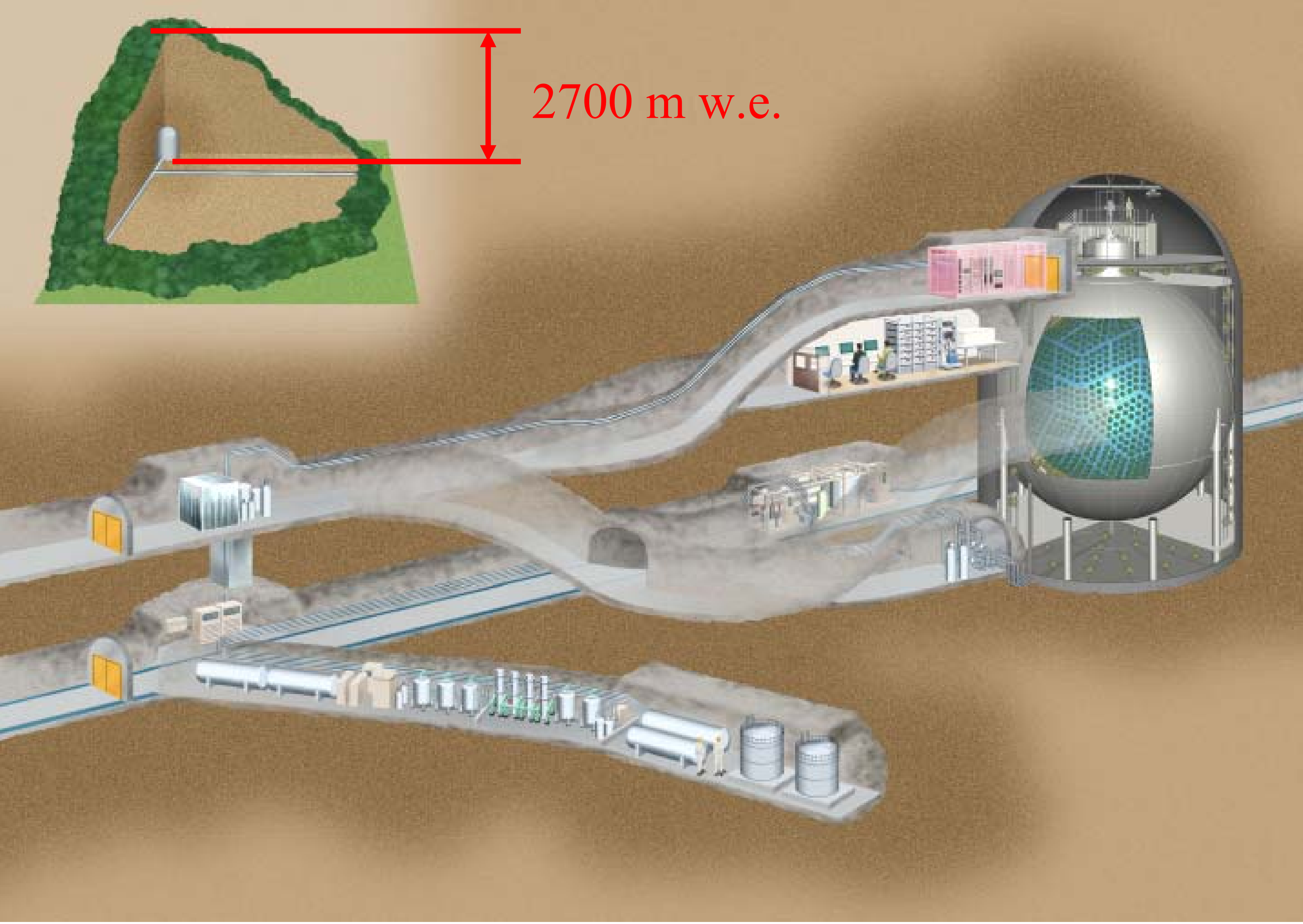
T. Araki,[1] K. Eguchi,[1] S. Enomoto,[1] K. Furuno,[1] K. Ichimura,[1] H. Ikeda,[1] K. Inoue,[1] K. Ishihara,[1,*] T. Iwamoto,[1,*] T. Kawashima,[1] Y. Kishimoto,[1] M. Koga,[1] Y. Koseki,[1] T. Maeda,[1] T. Mitsui,[1] M. Motoki,[1] K. Nakajima,[1] H. Ogawa,[1] K. Owada,[1] J.-S. Ricol,[1] I. Shimizu,[1] J. Shirai,[1] F. Suekane,[1] A. Suzuki,[1] K. Tada,[1] O. Tajima,[1] K. Tamae,[1] Y. Tsuda,[1] H. Watanabe,[1] J. Busenitz,[2] T. Classen,[2] Z. Djurcic,[2] G. Keefer,[2] K. McKinny,[2] D.-M. Mei,[2,†] A. Piepke,[2] E. Yakushev,[2] B.E. Berger,[3] Y.D. Chan,[3] M.P. Decowski,[3] D.A. Dwyer,[3] S.J. Freedman,[3] Y. Fu,[3] B.K. Fujikawa,[3] J. Goldman,[3] F. Gray,[3] K.M. Heeger,[3] K.T. Lesko,[3] K.-B. Luk,[3] H. Murayama,[3] A.W.P. Poon,[3] H.M. Steiner,[3] L.A. Winslow,[3] G.A. Horton-Smith,[4] C. Mauger,[4] R.D. McKeown,[4] P. Vogel,[4] C.E. Lane,[5] T. Miletic,[5] P.W. Gorham,[6] G. Guillian,[6] J.G. Learned,[6] J. Maricic,[6] S. Matsuno,[6] S. Pakvasa,[6] S. Dazeley,[7] S. Hatakeyama,[7] A. Rojas,[7] R. Svoboda,[7] B.D. Dieterle,[8] J. Detwiler,[9] G. Gratta,[9] K. Ishii,[9] N. Tolich,[9] Y. Uchida,[9,‡] M. Batygov,[10] W. Bugg,[10] Y. Efremenko,[10] Y. Kamyshkov,[10] A. Kozlov,[10] Y. Nakamura,[10] C.R. Gould,[11] H.J. Karwowski,[11] D.M. Markoff,[11] J.A. Messimore,[11] K. Nakamura,[11]

KamLAND is a 1000 ton liquid scintillation detector operated in Kamioka (Japan).

KamLAND successfully demonstrated electron anti-neutrino oscillations in the solar Δm^2 range.
Anti-neutrinos emitted (mainly) by Japanese nuclear power reactors are utilized.

<u>Other physics addressed by KamLAND:</u>

- Flux limit for solar anti-neutrinos
- Detection of geo-neutrinos
- Neutron disappearance (coming soon)
- Direct detection of solar ^{7}Be neutrinos


2700 m w.e.

○ **Detector site : Old Kamiokande site (2700 m.w.e.)**

○ **1,000 ton Liquid Scintillator**

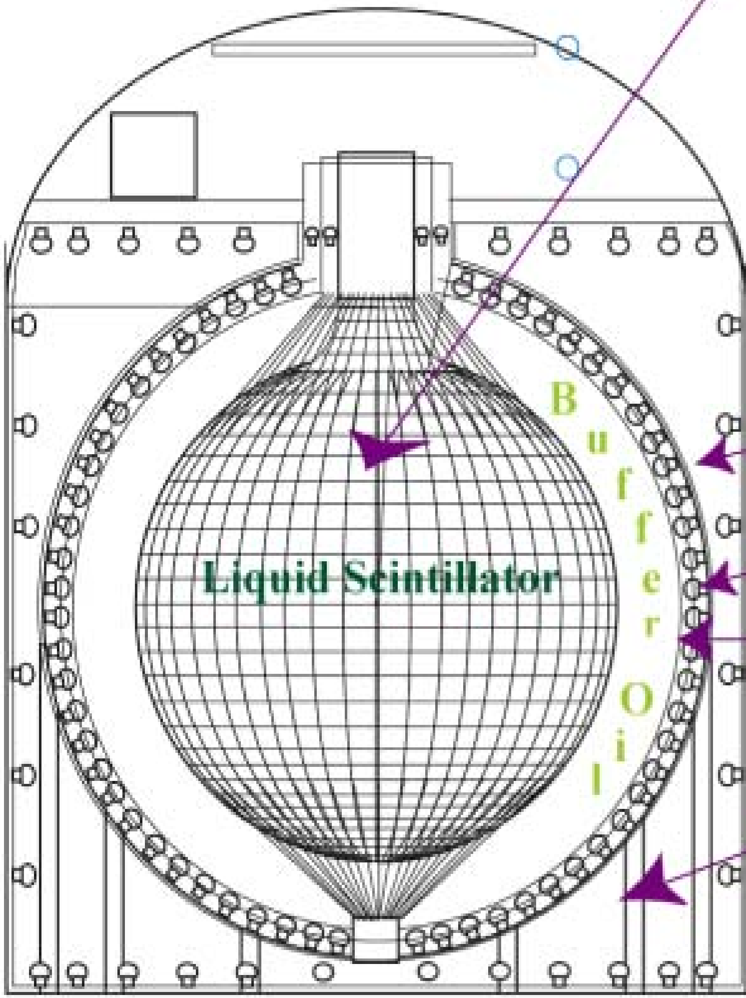
80%: dodecane, 20%: pseudocumene, 1.5 g/liter: PPO

(ρ= 0.78)

housed in spherical balloon (13m diameter)

of transparenet nylon/EVOH composite film (135 m)

supported by cargo net structure



○ **3,000 m^3 Scintillation Light Detector**

○ **18m diameter stainless steel tank filled with paraffin oil (ρ = 0.04%, lighter than LS)**

○ **1,325 17-inch+554 20-inch PMT's**

photosensitive coverage ~ 34 %

○ **3mm thick acrylic wall (120 plates)**

: Rn barrier

○ **Water Cherenkov Outer Detector**

225 Kamiokande 20-inch PMT's

For anti-neutrino detection use inverse beta decay:

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

$$n + p \rightarrow d + \gamma(2.2\,\mathrm{MeV})$$

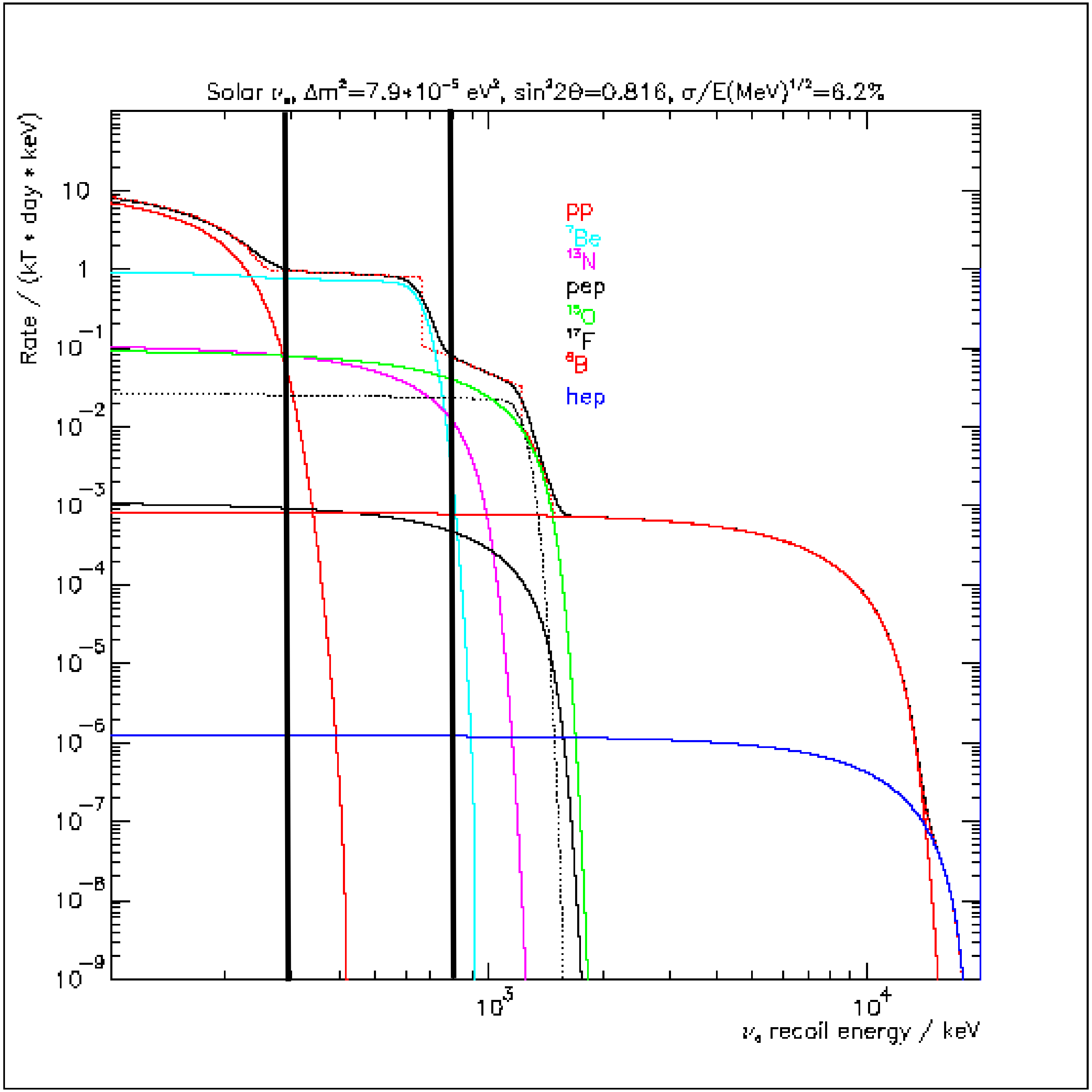
Average only one event every 2 days (R < 5.5 m, M=543.7 tons)! Very specific event signature through delayed coincidences.

Detection of solar neutrinos through elastic scattering:

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

→ Recoil spectrum

For ^{7}Be solar neutrinos expect about ~130 events per day (R < 5.0 m, M=408 tons). High rate but very unspecific signal.



Yield $(\mathrm{kt \cdot day})^{-1}$ for energy integration: 280 – 800 keV

pp : 1.6

^{7}Be : 272

pep : 12.6

CNO: 55.6

^{8}B : 0.4

hep : 0

What is the current detector background?

1. External radioactivity
2. Cosmic ray induced radioactivity
3. Internal radioactivity

→ Deduced from data and Monte Carlo

- Dominant external background for ^{7}Be is due to ^{40}K and ^{210}Tl γ rays

- ^{40}K and ^{210}Tl γ background estimation

  R = 4m fiducial volume cut:

  ^{210}Tl $< 5.6\ \mu$Hz, ^{40}K $< 3.4\ \mu$Hz

  (^{7}Be neutrino ~ 1 mHz)

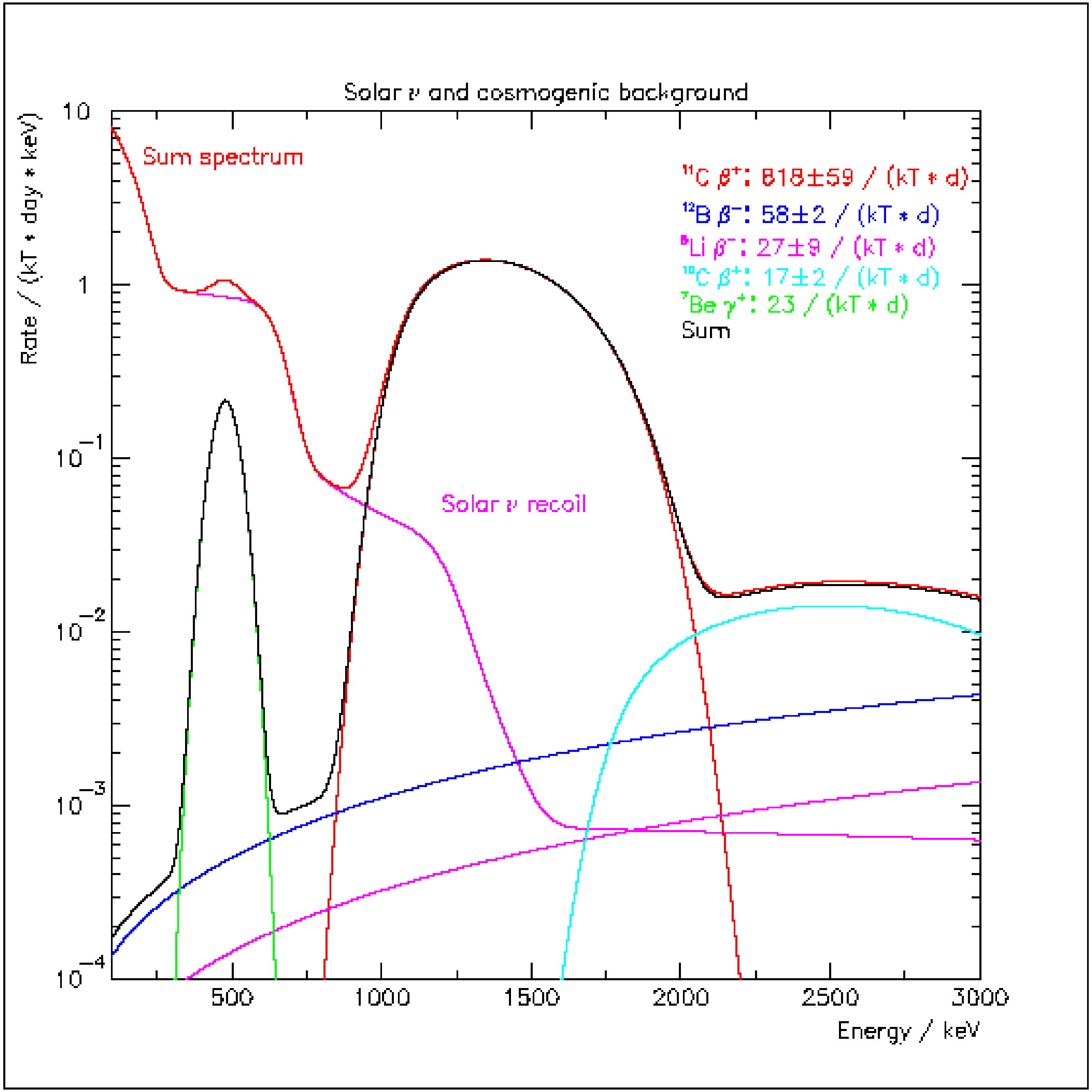
External background is acceptable. Couldn't be fixed anyway!

2. Cosmic ray induced radioactivity

Most cases determined from data. Tagged by veto and in some cases by delayed neutron capture.

Nuclide	τ	Q value [MeV]	Measured [Dcs / (kt · d)]	Hagner et al. SU
^{12}N	15.9 ms	17.3 (β^+)	<0.6	
^{12}B	29.1 ms	13.4 (β^-)	57.9±0.4	
^{9}C	192.5 ms	16.5 (β^+)	3.1±0.8	5.5
^{8}B	1.11 s	18.0 (β^+)	<0.92	8
^{8}Li	1.21 s	16.0 (β^-)	26.8±9.2	5
^{11}Be	19.9 s	11.5 (β^+)		<2.4
^{10}C	27.8 s	3.65 (β^+)	20.6±1.5 (n tag)	139
^{11}C	29.4 m	1.98 (β^+)	1049±66 (n tag)	1039
^{7}Be	76.9 d	0.478 (EC)		231

I. Shimizu



Yield $(\text{kt}\cdot\text{day})^{-1}$ in:
280 – 800 keV

^{11}C: 0.001
^{12}B: 0.3
^{8}Li: 0.08
^{7}Be: 23.1

Solar yield:
340 / (kt·day)

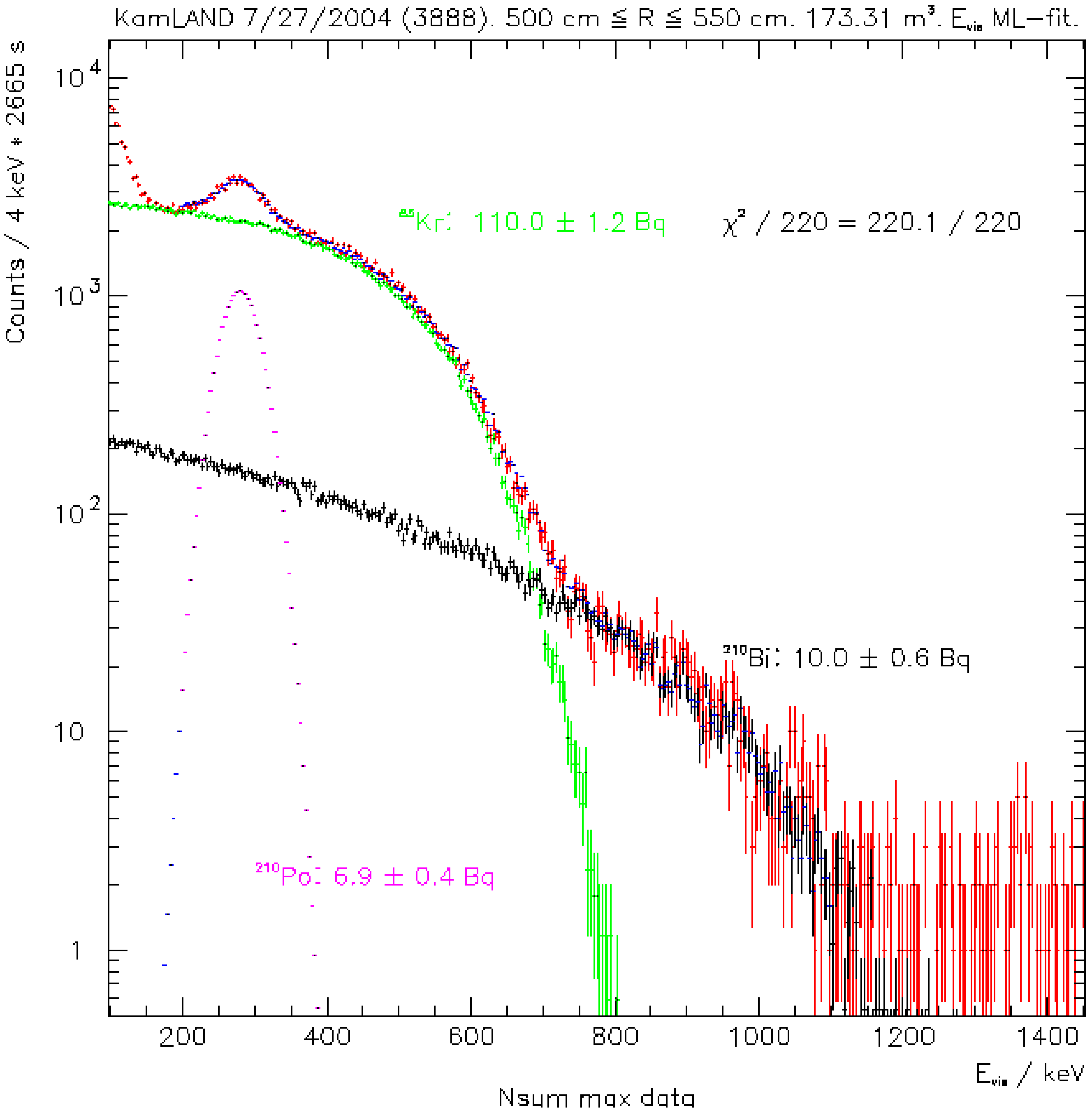
Overburden OK

3. Internal radioactivity

Relevant radio nuclides are:

- ^{14}C
- ^{40}K
- ^{85}Kr
- ^{210}Pb
- ^{232}Th / ^{220}Rn
- ^{238}U / ^{222}Rn

Determined from low threshold data and in case of Th and U through Bi-Po β–α delayed coincidences.



KamLAND 7/27/2004 (3888). 500 cm ≦ R ≦ 550 cm. 173.31 m³. E_vis ML−fit.
Counts / 4 keV * 2665 s
85Kr: 110.0 ± 1.2 Bq
χ² / 220 = 220.1 / 220
210Bi: 10.0 ± 0.6 Bq
210Po: 6.9 ± 0.4 Bq
E_vis / keV
Nsum max data

Measured Activities in KamLAND

	$T_{1/2}$	Current KamLAND Concentrations	Purification Goal	
^{14}C	5730 y	0.5 Bq/m^3	0.5 Bq/m^3	**OK**
^{210}Pb	22 y	60 mBq/m^3	0.6 $\mu Bq/m^3$	
^{40}K	10^9 y	$1.9 \cdot 10^{-16}$ g/g	10^{-18} g/g	
^{85}Kr	11 y	700 mBq/m^3	1 $\mu Bq/m^3$	
^{238}U	10^9 y	$3.5 \cdot 10^{-18}$ g/g	10^{-18} g/g	**OK**
^{232}Th	10^{10} y	$5.2 \cdot 10^{-17}$ g/g	10^{-16} g/g	**OK**

How to purify the KamLAND scintillator?

Reducible Backgrounds

- ^{85}Kr, ^{40}K, ^{210}Pb, ^{210}Bi, ^{210}Po, ^{222}Rn
- The KamLAND Collaboration is currently studying the effects of
  - Distillation
  - Nitrogen Purging
  - Adsorption
  - Heating

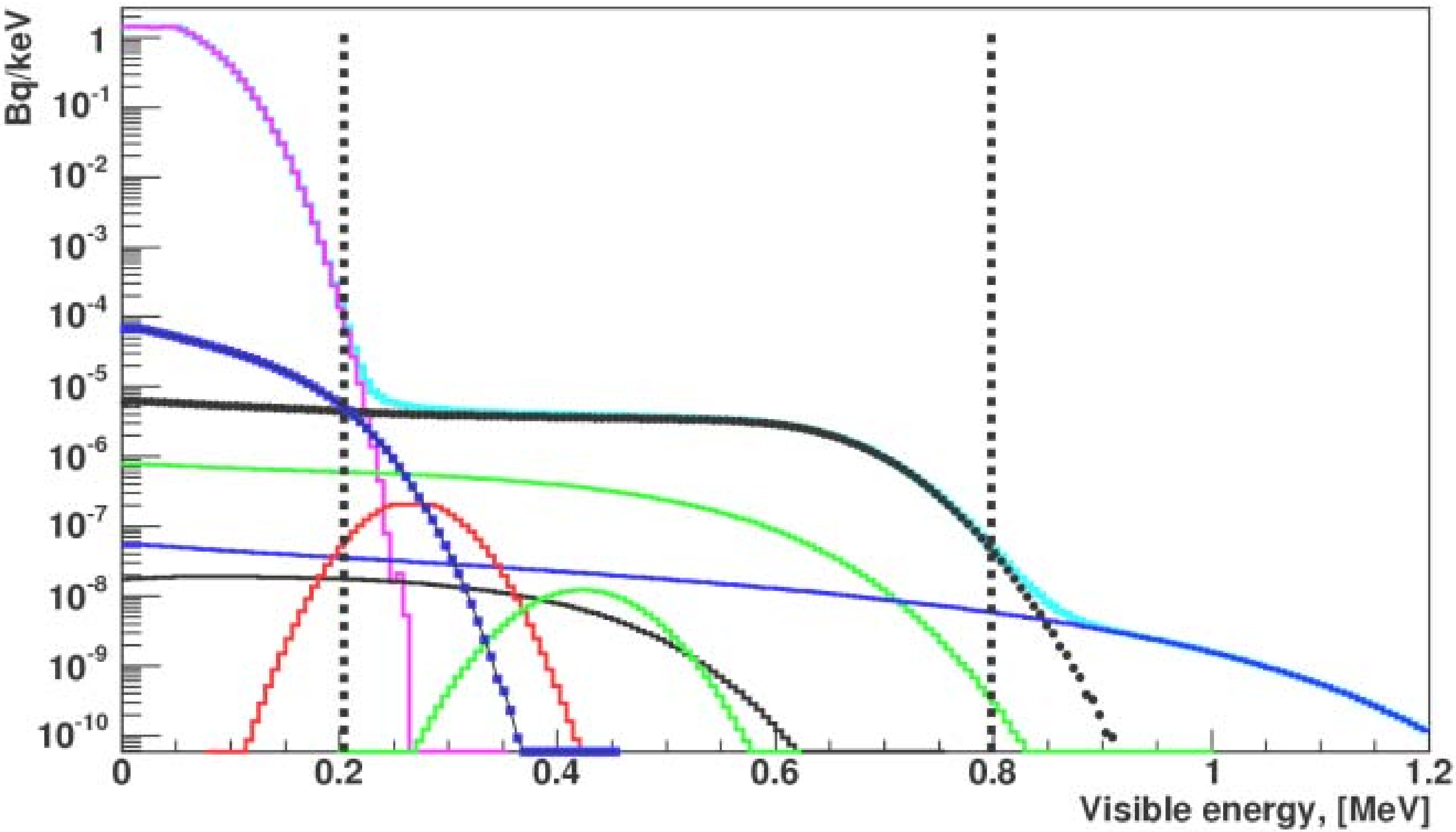
Being implemented now

on the removal of radioactive atoms and molecules from the liquid scintillator.

Being implemented now:

- High capacity Radon free liquid nitrogen generator. Multi stage refrigeration. Capacity 40 m^3/h (gas)
  Design goals: $^{39}Ar < 0.2\ \mu Bq/m^3$, $^{85}Kr \ll 1\ \mu Bq/m^3$, $^{222}Rn < 3\ \mu Bq/m^3$.
- Rare gas purge system using nitrogen gas. Multi stage counter flow.
  Projected reduction factors: Kr 10^{-4} to $5 \cdot 10^{-4}$, Rn $5 \cdot 10^{-4}$ to $7 \cdot 10^{-3}$
- Three column fractional distillation. Expected reduction: Kr 10^{-5} (by GC), Rn $\sim 10^{-6}$ (by Bi-Po), Pb 10^{-4} (via ^{212}Pb and Bi-Po).

Purification capacity: one volume exchange per month.



If 10^{-6} purification is achieved:

S : B (radioactivity 250 – 800 keV) 6:1

A. Kozlov

After 10^{-6} purification ^{7}Be solar neutrino signal can be extracted in two different ways:

1. Spectral analysis of signal and background. Good statistical accuracy can be reached ±5%

2. If spectrum is featureless or not well understood or desired purification factors cannot be achieved use annual flux variation (1.7%).
   10^{-6} and 5 years: 10% accuracy
   10^{-5} and 3 years: 20% accuracy

Distillation Pilot Setup

^{nat}Kr Reduction: 10^5

Measured by GC

^{222}Rn Reduction: 10^6

Measured by β-α coincidence of ^{214}Bi – ^{214}Po decay (233 μs)

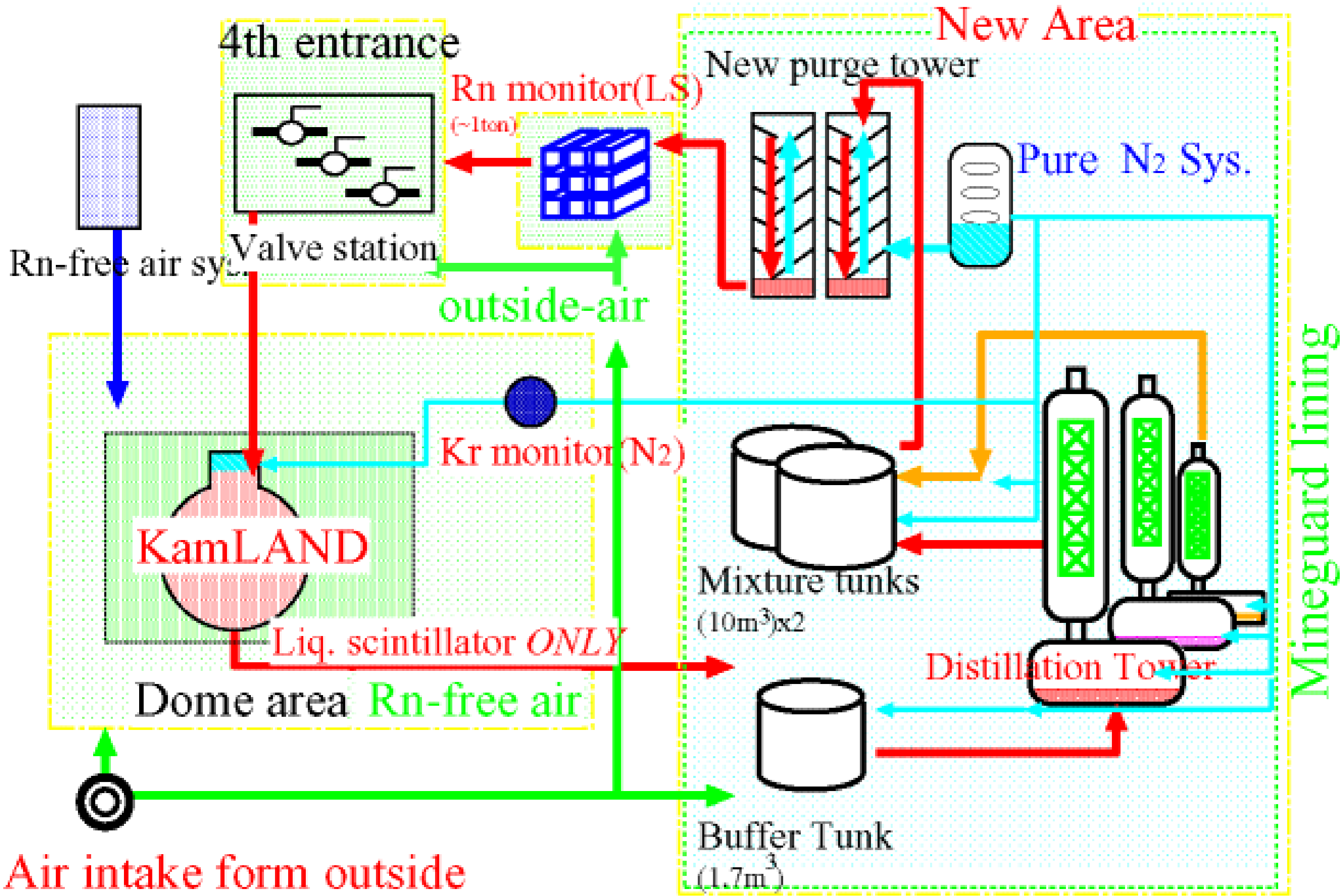
^{212}Pb Reduction: 10^4

Measured by β-α coincidence of ^{212}Bi – ^{212}Po decay (0.43 μs)

Operates at 1-2 l/hr

Inline Monitoring During Purification

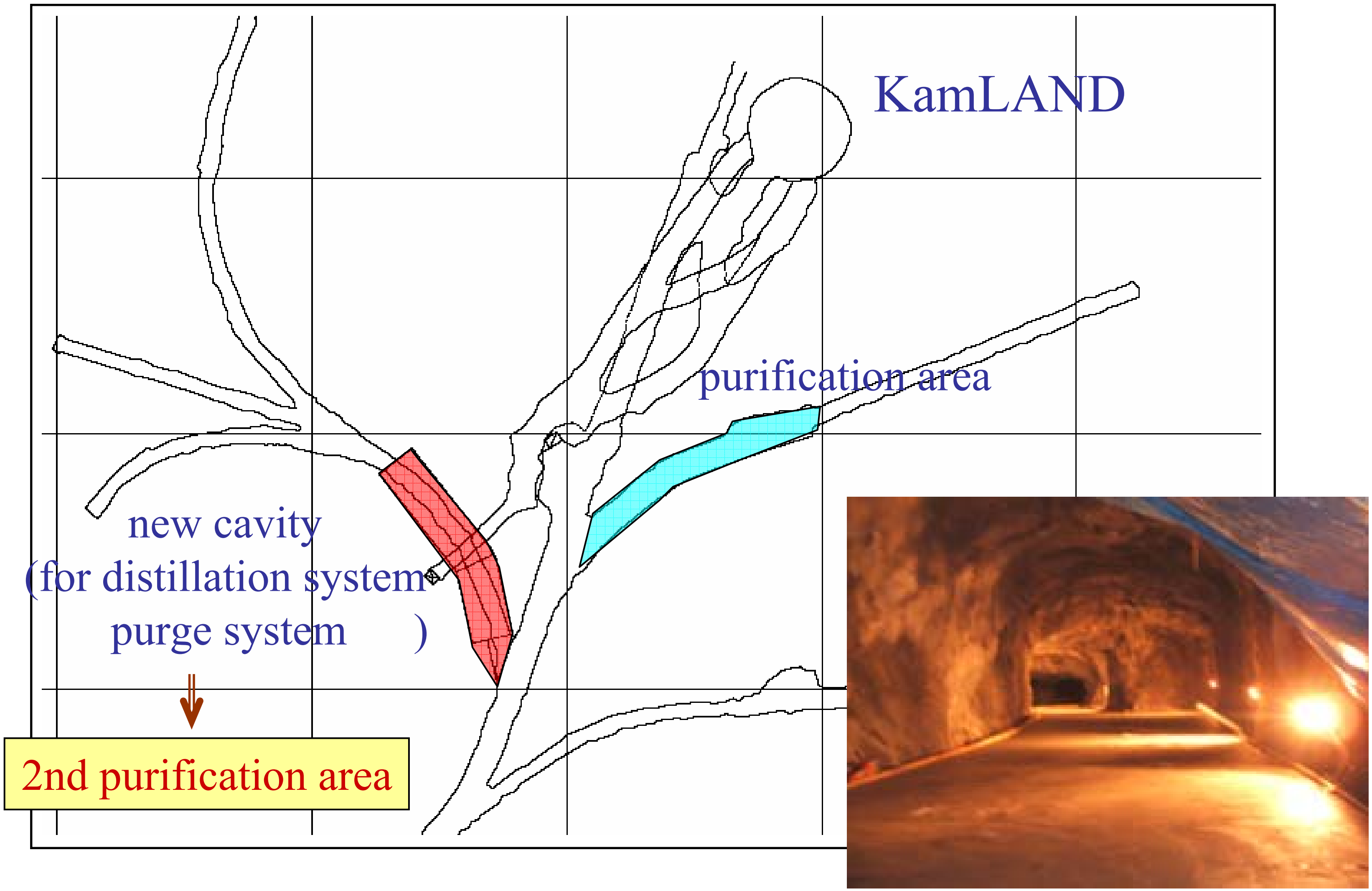
- Purpose is to insure that we are obtaining high levels of purification and not re-contaminating after purification procedure.
- ^{85}Kr measurement system which will increase our sensitivity to low concentrations by using a cold trap and then passing through an RGA.
- ^{222}Rn measurement (mini-KamLAND)
- Other activities (U, Th, ^{210}Pb) are too low to measure without a detector like KamLAND or long counting times.



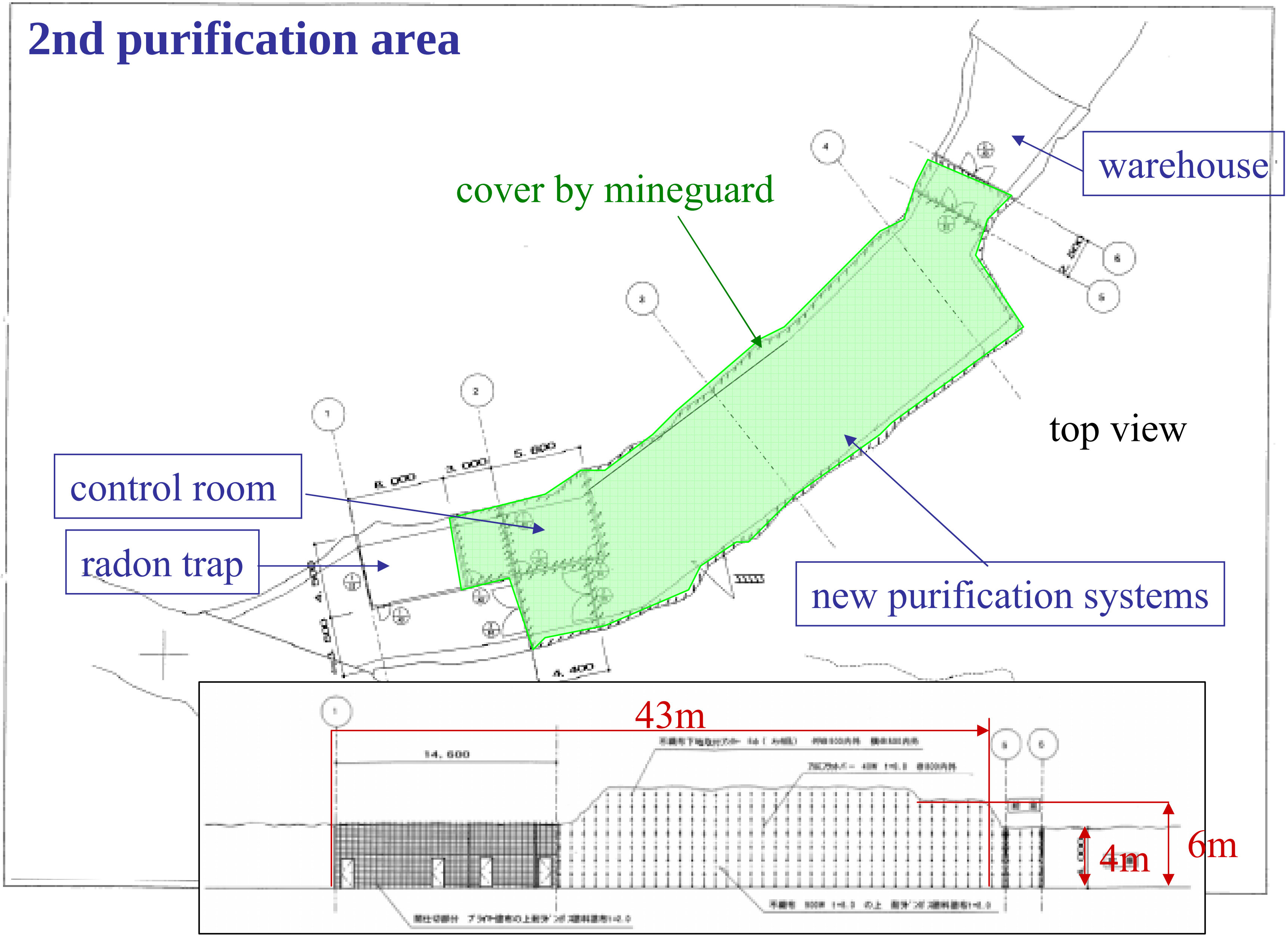
4th entrance
Valve station
Rn monitor(LS)
(~1ton)
Rn-free air sys.
outside-air
New Area
New purge tower
Pure N2 Sys.
Kr monitor(N2)
KamLAND
Mixture tunks
(10m^3)x2
Liq. scintillator ONLY
Distillation Tower
Mineguard lining
Dome area
Rn-free air
Buffer Tunk
(1.7m^3)
Air intake form outside

Y. Kishimoto

• New purification hall has been built.



2nd purification area



Construction related to new purification system

• partition with concrete blocks and steel doors	Nov. ’05
• mineguard coating of inner surfaces	Dec.’05 ~ Jan.’06
• move low Rn air system to new cavity	Feb.’06
• higher grade LN2 system installation	Feb. ~ Mar.’06
• installation of lights, fire sensors and Rn less air supply pipes	Feb.’06
• N2 purge towers installation	~ Mar.’06
• exchange electricity from mine power to Hokuriku electricity company one.	~ Jul.’06
• installation of the distillation system	~ Aug.’06
• purification test operation will start	Aug.’06 ~

Conclusion

- Different scintillator purification methods have been studied during the last 2 years.
  Reduction factors of order 10^5 for Kr, Pb and Rn could be demonstrated in the lab and a new mid scale pilot plant.
- Initially a Nitrogen purging and distillation system are being built, allowing one volume exchange per month.
  Options for re-fitting of adsorption columns are kept open, if needed.
- We are planning to commence test operations by August 2006.

- Scintillator purification will benefit the reactor and geo-neutrino program through the reduction of αn background.

- If the large purification factors observed in lab tests can be realized then the direct determination of ^{7}Be neutrinos, with high statistics, would be possible. We hope to achieve 5 to 10% measurement.

- This is a tough technical challenge. Stay tuned!